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ACCIDENTAL RELEASE OF AMMONIA FROM A STORAGE TANK AND THE EFFECTS OF ATMOSPHERE ON THE AFFECTED AREA USING ALOHA

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ABSTRACT

Chemical accidents are getting more frequent with increasing industrialization and increased handling of large quantities of chemicals. The worst chemical accident, Bhopal gas tragedy reveals that preparedness is the only precaution and we can adopt to reduce the impact. For an effective preparedness, it is necessary to understand the influencing factors, which make the situation highly dangerous. As the atmosphere has a decisive influence on the dispersion of the chemical which become airborne when it is released from a storage tank, it is necessary to understand how different atmospheric parameters influence the dispersion of gas clouds. This study aim to assess the impacted area of ammonia toxicity from a storage facility under different atmospheric conditions of a day. Three different times of a day and one night time were taken into consideration for modeling. The atmospheric variables taken into account are temperature, wind speed, humidity, and stability condition. The air dispersion model ALOHA (Areal Locations of Hazardous Atmosphere) is used in this study to model the impacted distances of ammonia leaks. The result shows that there is a significant difference in the impacted area of an ammonia leak under different conditions.

KEYWORDS: Ammonia, ALOHA, Chemical Accident

In recent years we have been witnessing a number of disasters resulting in fatalities and injury of large number of people. Natural disasters related to climate can be predicted. In contrast, chemical disasters associated with chemical storage and transportation can't be foreseen as it is unexpected, either due to human error or infrastructure errors. Bhopal gas tragedy (1982), Vapor Cloud Explosion of LPG in HPCL Refinery at Visakhapatnam (1997), LPG Tanker Accident at Chala, Kannur (2012) etc., happened in the past, revels the fact that chemical accidents are mainly due to human carelessness (Broughton; 2005 Faisal and Abbasi; 1999, Pramod ; 2013). In spite of strict rules and regulations for the enforcement and monitoring of chemical safety and emergency management (NDM Guidelines; 2007) exist, still the above accidents claimed a number of lives. As such incidents happen unexpectedly, preparedness to handle such situations seems to be essential in securing the right to life and to reduce the anticipated impact (WHO; 2007). For an effective preparedness, it is necessary to assess the severity of incident.

Major outcomes of chemical disasters are in the form of fire, explosion, and toxic releases (James; 2006). The chemical which become air borne when it is released from a storage tank have drawn more attention due to their potential to damage larger areas dispersing through the air (Carson and Mumford; 1994). The severity of incident depend upon the extent of exposure that can be influenced by the number of factors such as quantity of the substance released, characteristics of the chemical, prevalent weather conditions, mitigation measures, and the proximity to the point of release (USEPA,1999). During its dispersal, the prevailing atmospheric conditions play a decisive role in the extent of spreading (Zhu et al; 2013, Truong et al 2016).

Though the toxic or flammable clouds of heavy gases are transported mainly in the wind direction, its dispersion also will be perpendicular as well as vertical to the wind direction. Besides, the wind velocity direction, other meteorological variables which influence the atmospheric dispersion of heavy gas clouds are atmospheric turbulence (stability), humidity and temperature (Casal; 2008). A stable atmosphere inhibits the vertical mixing of gas clouds. In such conditions, the gas clouds are transported by the wind to a long distance horizontally. While, an unstable atmosphere enhances vertical mixing whereas a neutral atmosphere neither enhances nor inhibits vertical mixing. Solar radiation plays a decisive role in the stability conditions of the atmosphere. Above all, these meteorological variables can vary on a daily basis or with the season. Also, the dispersed area of heavy gas cloud varies with different atmospheric conditions. Therefore, it is essential to understand the effect of dispersion under different atmospheric conditions for formulating effective preparedness strategies to tackle chemical accidents. Considering all these factors, this study modeled the dispersion of ammonia under typically different atmospheric conditions and assessed the difference in the spatial extent as well as intensities in the impacted area.

In chemical accident modeling the term dispersion is used to describe the diffusion of toxic or flammable gas or vapor in the atmosphere. There are several ways to model the dispersion of hazardous chemicals. Different from the traditional way of

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mathematical modeling, nowadays the outcomes of accident scenario can be achieved by using the consequential modeling combined with various computer software (Harbawi et al; 2008). This study uses one such sofrware, ALOHA (Areal locations of Hazardous Atmosphere), to model the effect of atmosphere on the dispersion of release of ammonia. This software developed and supported by the National Oceanic and Atmospheric Administration (NOAA) in collaboration with US EPA (Environmental Protection Agency), is able to process necessary calculations to simulate the dispersion of chemical using various input data related to release scenario (NOAA). This software is designed to respond in short time and give accurate results by checking the user's input errors (Mehdi et al; 2017). The model has been used in numerous studies to analyze the downwind concentration of various hazardous chemicals such as Ammonia, LPG, Chlorine, Benzene etc (Inanloo and Tansel; 2015, Angela et al; 2010, TSENG et al; 2012, Renjith; 2010) reveals its advantages in consequence modeling.

STUDY AREA

A port-based refrigerated ammonia storage tank kept at atmospheric pressure located at Willingdon Island, a part of Cochin Corporation, pose sever threat to the neighboring community due to the storage and handling of large quantities of ammonia. The position of the tank is at 9^0 57'13" Latitude and 76^0 16'03" longitude near the lake of Kochi. Though the island is less inhabited with permanent residents, commercial areas such as trading centers, offices, hotels, and tourist homes make the area highly populated. The Island also serves home to the Kochi Naval Base and Port of Kochi. Though the position of the ammonia storage tank is in uninhabited area, in case of ammonia release, the toxic vapor clouds can spread to the nearby densely populated areas of Cochin Corporation. It was alleged that the 10,000-tonne capacity tank was capable of turning Kochi into another Bhopal (The Hindu; 2014).

MATERIALS AND METHODS

Weather Information

ALOHA require information about the conditions in the vicinity of an accidental release such as wind speed and direction, ground roughness, air temperature, cloud cover, inversion height, relative humidity and stability class. To determine indoor infiltration rate and indoor concentration, the model takes information about building type, wind speed and air temperature. ALOHA uses relative humidity to estimate the atmospheric transmissivity and make heavy gas dispersion. The core factor in ALOHA's dispersion model is the stability classification. The two factors which determine the stability class in ALOHA are solar insolation and wind speed. Information on date, time, location, and cloud cover are used to determine the solar insolation (NOAA and U. S EPA; 2007). Stability of the atmosphere influences largely the dispersion of gases in the atmosphere (Canepa et al; 2000). Since turbulence intensity cannot be measure directly, correlations are sought to indicate stability class as a function of readily measurable variables (John and Woodward; 1998). Stability classes are determined for different meteorological conditions, which are dependent on wind speed and solar isolation during the day and cloud cover during the night (Pasquill; 1961), which classifies the atmospheric conditions from stable to unstable. Paquill-Gifford stability classes include six classes characterized by wind speed and solar radiation and cloud cover as described below in the table 1.

Table 1: Pasquill

Classes	Stability Condition
A	Very unstable
B	Unstable
C	Slightly unstable
D	Neutral
E	Stable
F	Very stable

Stability Classes

A, B, C are typical daytime stability classes and start increasing significantly around 0700 hours in the morning and stop decreasing significantly at around 1700 hrs. E, and F only occur at night time. The neutral class D can occur during the day or night according to wind conditions or transform times of dawn and dusk (Magidi; 2013). Night refers to the period from 1 hour before sunset to 1 hour after sunrise (Turner and Bruce; 1994).

To estimate the spatial extent of ammonia release from a storage tank under different atmospheric conditions four different time of the day (morning, noon, evening, and night) were selected and corresponding value of atmospheric parameters were analyzed using ALOHA. Each of the time taken is considered as each scenario (Scenario I, II, III, and IV). Atmospheric variables taken are wind speed, temperature, humidity and stability of the atmosphere. To model the atmospheric dispersion in a representative way, average values of these variables for a winter month (January), when the atmosphere is least turbulent were taken. The values entered are given in table 2.

Table 2: Atmospheric Parameters used for analysis

Scenarios	Time	Temperature	Wind speed	humidity	Stability Class
I	03.00(Night)	25^0C	8km/h	89%	E
II	08.00(Morning)	25^0C	8km/h	85%	C
III	01.00(Noon)	34^0C	13km/h	60%	B
IV	05.00(Evening)	31^0C	15 km/h	72%	C

Source: https://www.timeanddate.com/weather/india/kochi/hourly

Properties of Chemical

ALOHA's calculations require information about properties of the chemical and its data file includes information about physical properties of all the chemicals which are usually involved in accidental releases. As mentioned in the introductory section, this study highlighted the accidental release of ammonia from a storage tank and its properties are given below:

Molecular weight: 17.03 g/mol

Ambient boiling point : -33.4^0C

Vapour pressure at atmospheric temperature : greater than 1 atm

Ambient saturation concentration : 1,000,000 ppm or 100.0%

Based on molecular weight, size of the tank, and temperature of the gas cloud, ALOHA simulate the effect of Gaussian or heavy gas release (Robert et al; 2013). Ammonia is lighter than air at room temperature, but are stored in a cryogenic state (low temperature), can form heavy gas clouds when released in to the atmosphere (Zohuri, 2017). If the density of the gas is substantially greater than the density of the air (1.1kg/m3), ALOHA considers the gas to be heavy and performs heavy gas modeling.

Ammonia is stored in tanks as liquid, but will expand by 850 times when exposed to the atmosphere. It is a colorless gas, but with a very sharp odor. Anhydrous ammonia is classified by the department of transportation as nonflammable, but ammonia vapor in high concentration, 16 to 25 percent by weight in air, will burn (OSHA). Ammonia is not a poison, but it is a toxic substance, even in small concentration in the air can be extremely irritating to the eyes, throat, and breathing passages. The odor threshold of ammonia is between 5-50 parts per million (ppm) and permissible exposure is 50 ppm averaged over an 8 hour period (U. S. EPA, 2001).

ALOHA's chemical library include toxic levels of Chemicals (LOC) such as AEGLs (Acute Exposure Guideline Levels), ERPGs(Emergency Response Planning Guidelines), IDLH (Immediate Danger to Life and Health), and PACs (Protective Action Criteria) and these values depend on the nature of the chemical. For the present study, ERPGs are taken into account for toxic LOC. ERPGs estimate the concentrations at which people will begin to experience health effects if they are exposed to a hazardous airborne chemical for 1 hour. The ERPGs were developed by the ERPG committee of the American Industrial Hygiene Association (ERPGs/weel hand book;2013, NOAA ERPGS).

Source Strength

ALOHA uses source strength models to estimate the amount of material becoming airborne or the rate at which the chemical become airborne. The source strength information required for modeling are described below:

Tank Diameter:38 meters

Tank length:14 meters

Tank volume:15,878 cubic meters

Internal temperature: -33.2^0C

Chemical mass in the tank:10000 tons

Shape of the opening through which the chemical is exiting: circular opening

Circular opening diameter: 2.2 inch meters

It is assumed that the chemicals are released through a 2 inch diameter valve and 100% diameter of the valve is taken into account. ALOHA links source strength models to air dispersion models to estimate the spatial extent of airborne release. The size and duration of a toxic cloud is significantly affected by the rate at which chemical become airborne.

RESULTS AND DISCUSSION

Four scenarios were modeled for four time periods of a day by using consistent atmospheric conditions and all other required information were provided as an input. ALOHA estimated the impact in the form of threat zones displayed in red, orange, and yellow where the hazard is predicted to exceed the LOC at some time after a release begins. Figure 1 shows the threat zones of scenario I, II, III and IV. It is considered that the concentration of the chemical will be high near the point of release and decreasing with the distance from it. In figure 1, the red zone represents the worst hazard zone and the orange and yellow are the zones of decreasing hazard.

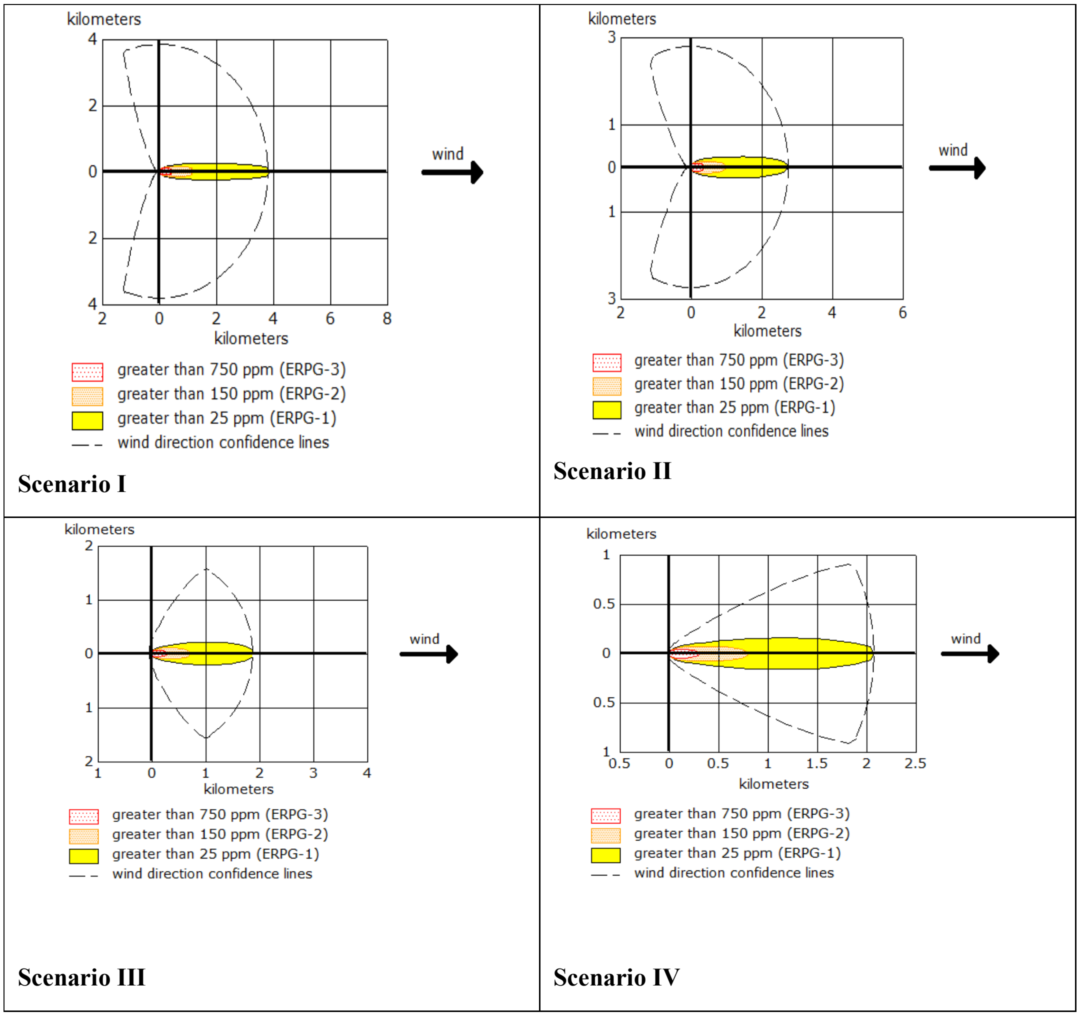

Figure 1: Impacted distance of ammonia toxicity under different atmospheric condition.

Scenario-I (night), Scenario-II (morning), Scenario-III (noon), Scenario-IV (evening)

The red is the ERPG-3 level, where the airborne concentration predicted is 750 ppm below which the people could be exposed up to 1 hour without experiencing or developing life threatening health effect. The maximum airborne concentration (predicted in ERPG-2 is 150 ppm), represents the orange zone below which people could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects. Yellow is the ERPG level-1, where the airborne concentration predicted is 25 ppm below which people could be exposed for 1 hour without experiencing more than mild, transient adverse health effects. As the wind changes its direction with time, wind confidence lines on the threat zone graph represents the uncertainty in the wind direction. The maximum impacted distance obtained for scenario-I overlaid on actual location on Google Earth is given in figure 2. It is clear from the figure that the threat zones are passing through densely populated area.

Figure 2: Ammonia toxicity impacted area (represent the largest impact observed for night time)

From figure 1, it is clear that the impacted area of ammonia differs under different atmospheric conditions. The release rate from the tank depends upon the driving pressure, nature of rapture and phase released (liquid, gas, or mixed phase). As per the source information provided, the estimated release rate is 140 kilograms/min and total amount released is 8,374 kilograms. Table 3 gives the impacted distance of ammonia under given conditions.

Table 3: Impacted distance of ammonia under different atmospheric conditions

Threat zones	Scenario I	Scenario II	Scenario III	Scenario IV
Red	411 m	341 m	294 m	313 m
Orange	1.2 km	990 m	723 m	795 m
Yellow	3.8 km	2.8 km	1.9 km	2.1 km

The table shows that maximum impacted distance is observed for scenario-I (3.8 km from the source), at night time and minimum distance is observed for scenario-III (1.9 km from the source), at noon time. It is clear that the stable atmosphere (E, for scenario-I) make the toxic cloud to move to larger distances than in the unstable condition (B, for scenario III). Meanwhile only a slight difference can be seen in the case of scenario-III and scenario-IV representing noontime and evening time respectively. But there is a significant difference in the affected area under stability class C in the morning time and evening time. The morning atmospheric condition allows the toxic clouds to move larger distance than in the evening.

The results show that all the atmospheric variables have an effect on the toxic clouds of ammonia affected area. The more stable atmospheric condition and low wind speed leads to longer toxicity impacted distance. During high wind speed, as the wind push the gas vapor clouds to disperse forward in its direction and the concentration of the cloud is diluted continuously, shorter affected distance is observed. The toxicity affected distance decreases with the reduction of stability class E, B and C. In short, it can be concluded that the stable atmosphere (class E) usually prevailing in the night time are more dangerous than day time.

CONCLUSION

A prior knowledge of effect of different atmospheric condition on the dispersion of denser gas clouds might be of great help for taking immediate management strategies in case of an ammonia leak in the storage facility. Stability is a concept used to characterize the low-lying atmosphere, influencing largely the dispersion of toxic clouds in the atmosphere. The study shows that varying atmospheric conditions largely influence the dispersion of ammonia gas cloud. A very stable atmosphere allows the gas clouds to move large distance and impact larger population. This is what happened in the Bhopal gas tragedy and lack of preparedness made the situation tragic. But the only precaution we can take is to anticipate the impact and be more prepared to reduce the effect when it happens unexpectedly. The study reveals that air dispersion model ALOHA will be a useful tool for such studies and help the emergency management personnel to prepare an effective management plan. But no generally applicable rule can be applied to understand the influence of atmosphere on gas dispersion because the intensity of the variables changes not only with the time, but also with the season. Therefore, further extensive studies are required to formulate readymade references in case of accidental ammonia releases.

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